Biovision team Helping visually impaired people Multi scale modeling of the retina

Bruno Cessac

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Submitted on 15 Oct 2018

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Multi scale modeling of the retina

Bruno Cessac

Biovision team

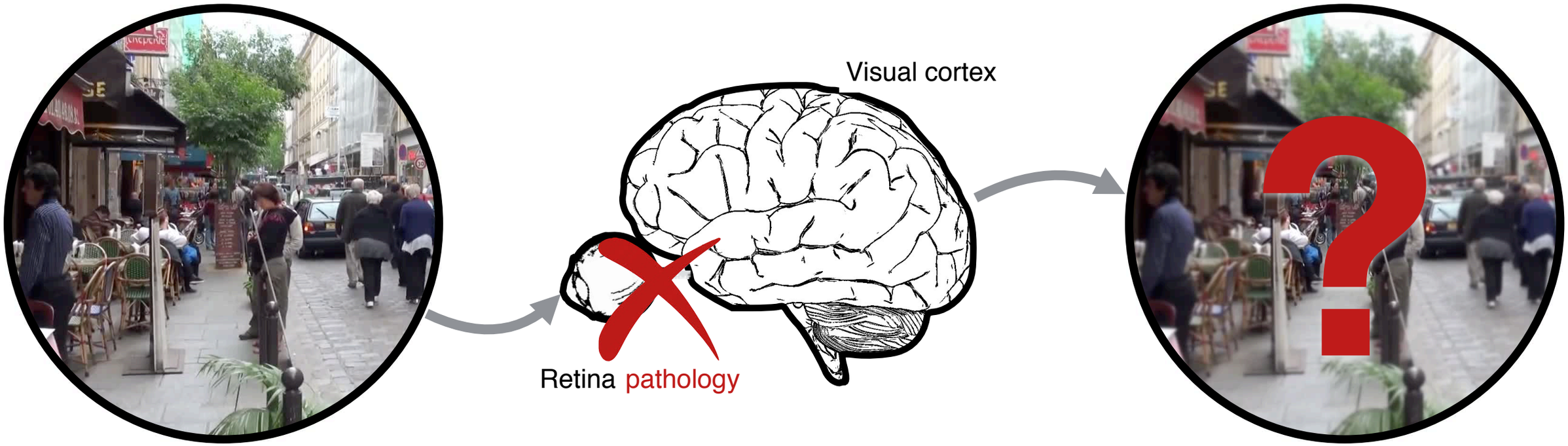
Helping visually impaired people

Helping visually impaired people

285 millions, x3 in 2050

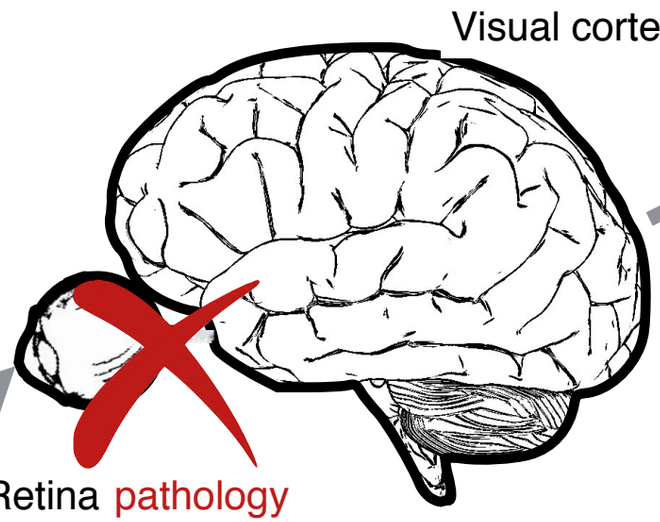
Helping visually impaired people

285 millions, x3 in 2050



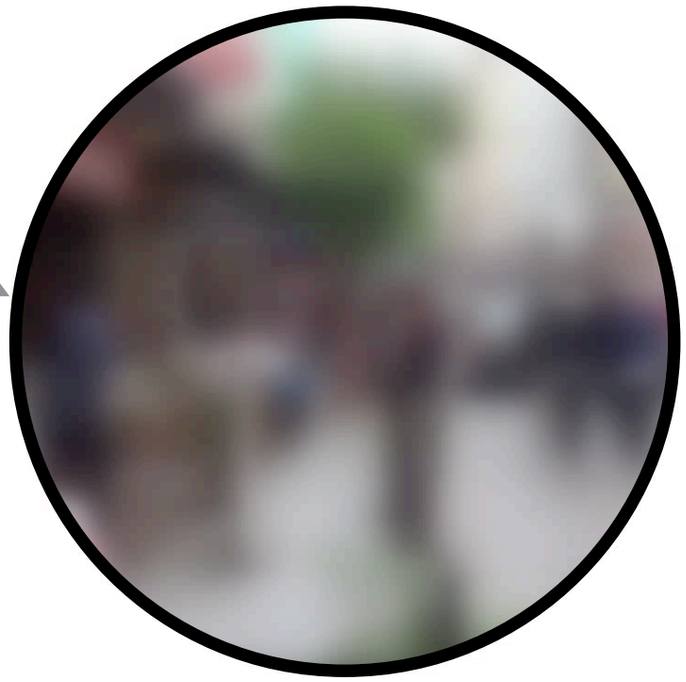
Helping visually impaired people

285 millions, x3 in 2050



Retina pathology

Degenerative myopia



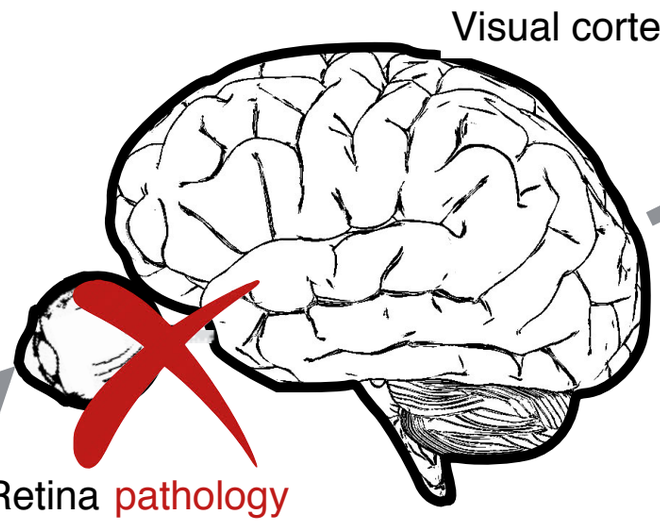
Local ✗ Global ✗

Details viewing
Reading

Scene understanding

Helping visually impaired people

285 millions, x3 in 2050



Retina pathology

Retinitis pigmentosa

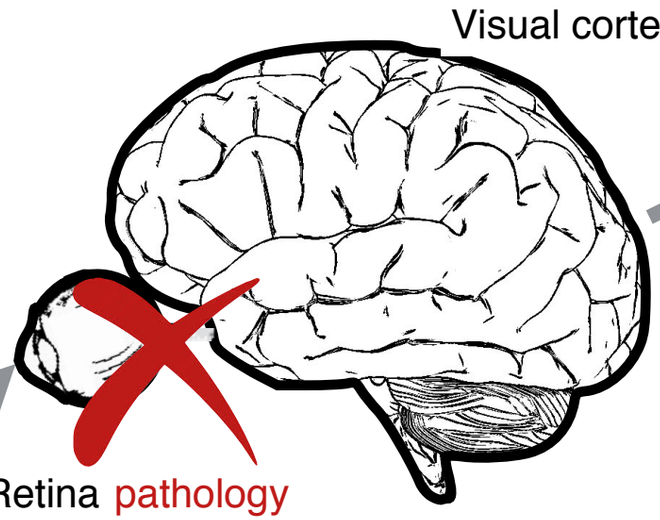
Local ✓

Global ✗

Scene understanding
Obstacle avoidance
Depth estimation

Helping visually impaired people

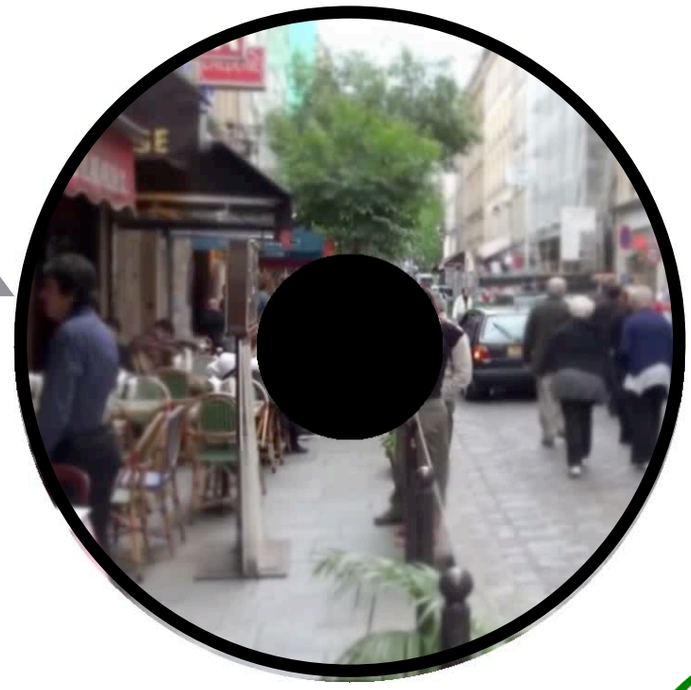
285 millions, x3 in 2050



Retina pathology

Age Macular Degeneration (AMD)

France: DMLA
1st cause, 1.5M, 1/4 after 75 y.o.

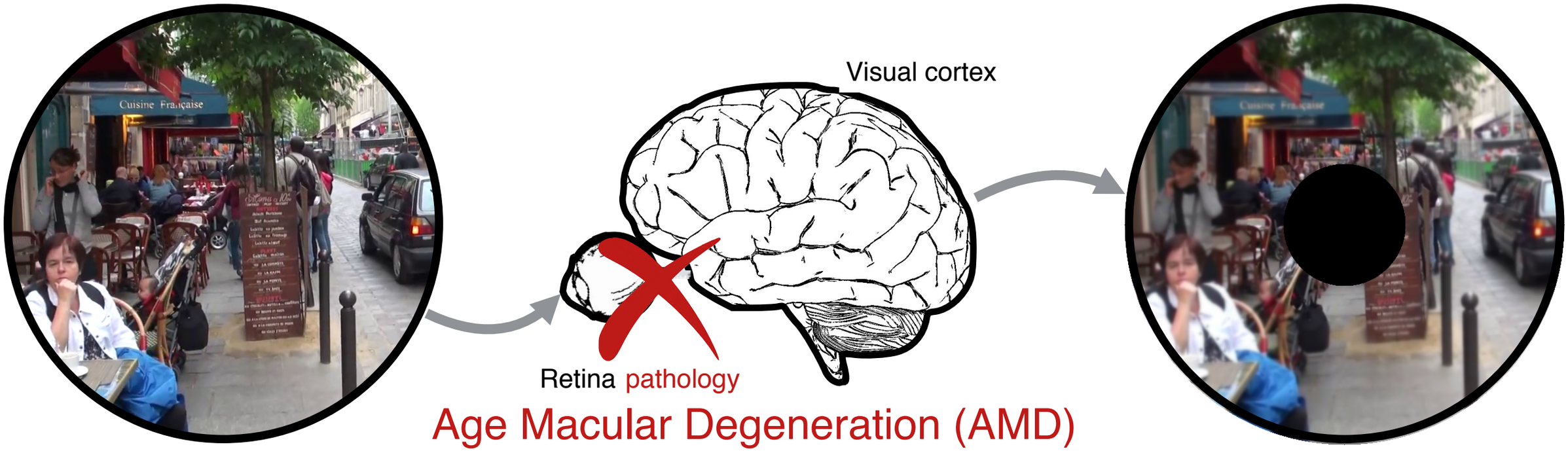


Local ✗ Global ✓

Details viewing
Reading

Helping visually impaired people

285 millions, x3 in 2050



Age Macular Degeneration (AMD)

New technics are emerging to help people use their remaining vision, slow down or even reverse vision loss

> New scientific and technological challenges
>
> New paradigms to understand vision
>
> New technological breakthroughs

Biovision team

Main goals

Models

Propose models of the visual system, normal and impaired

Simulation

Develop simulation tools for the early visual system + motion

Therapy

Help improving rehabilitation strategies (models, algorithms, software)

Accessibility

Design vision-aid systems to help patients in daily living activities

Biovision team

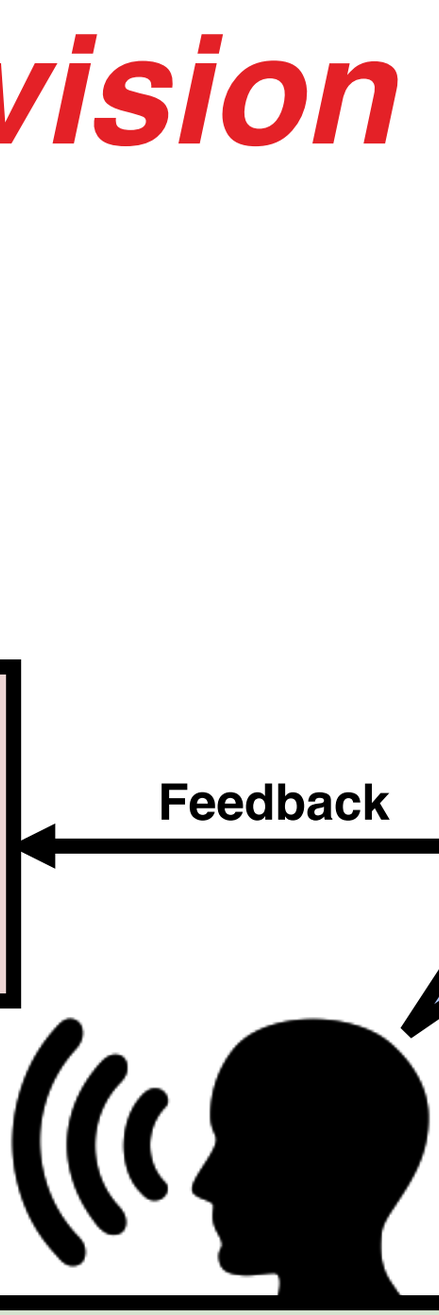
Computer vision and graphics

Scene analysis and enhancement
Dependent on pathology

Feedback

Perception

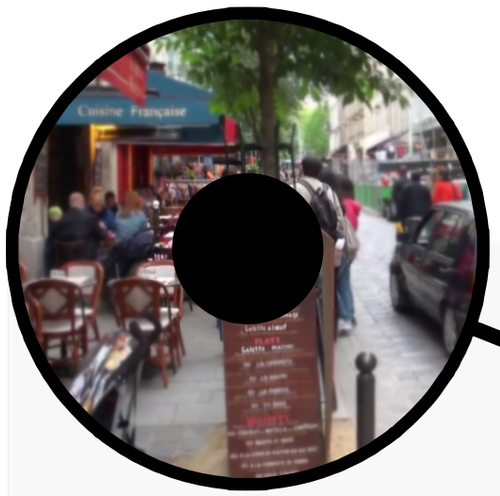
Psychophysics



Retina processing → Encoding → Cortex processing

Biophysical modeling, model analysis, visual system emulation

Biovision team



Computer vision and graphics

Scene analysis and enhancement
Dependent on pathology

Feedback

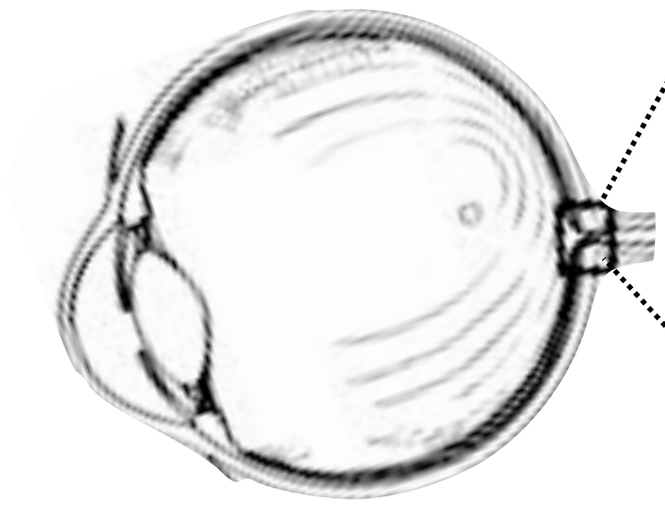
Perception

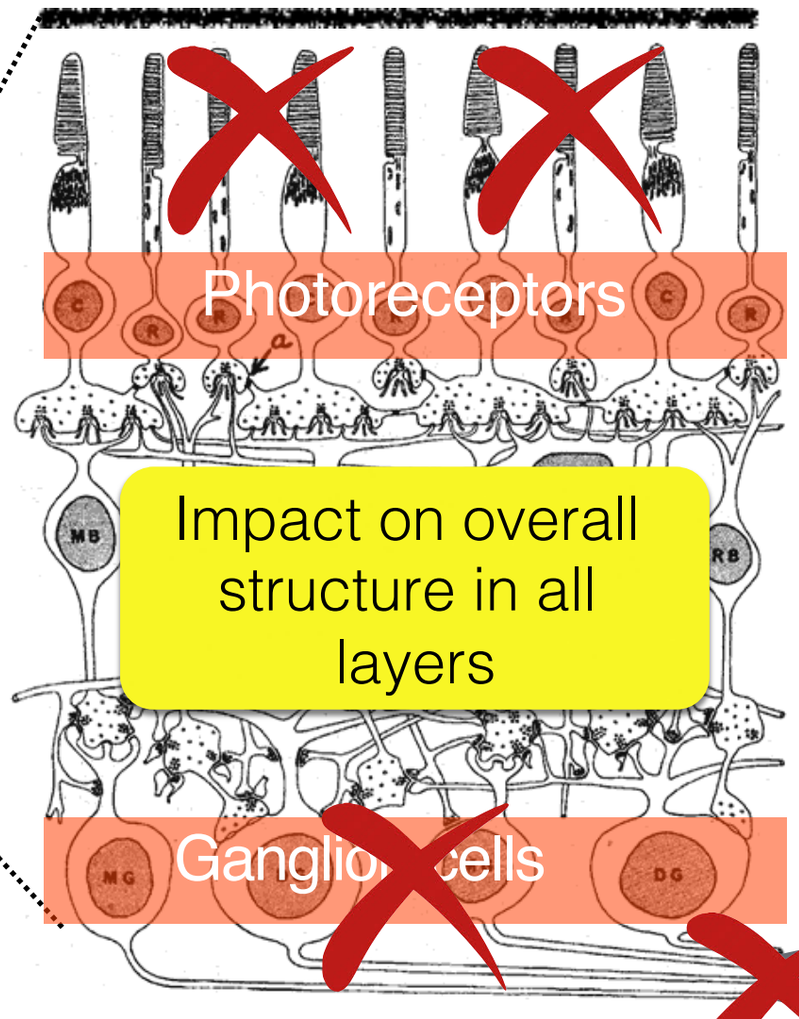
Psychophysics

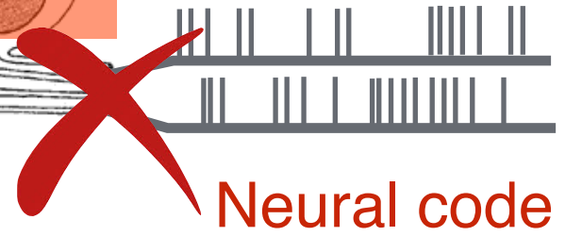
Retina processing → Encoding → Cortex processing

Biophysical modeling, model analysis, visual system emulation

The retina





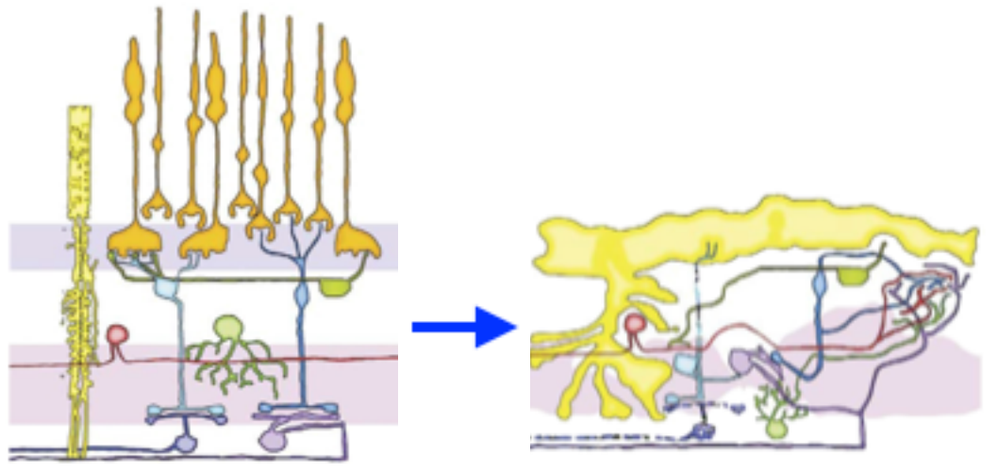


Neural code

Modeling retina pathologies

Software development and modelling

From healthy retinas to impaired ones



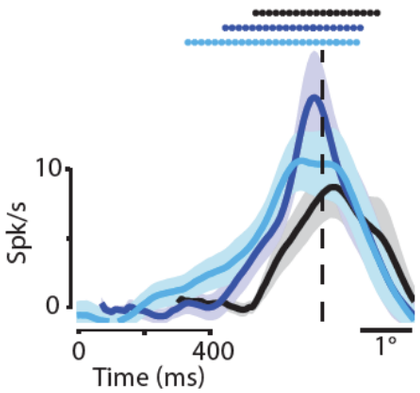
Multi-scale modelling and simulation

Individual cells characterisation

Collective activity and coding

Mesoscopic description

Focus on motion and anticipation



D. Karvouniari, PhD (2014-2018)
Dir.: B. Cessac

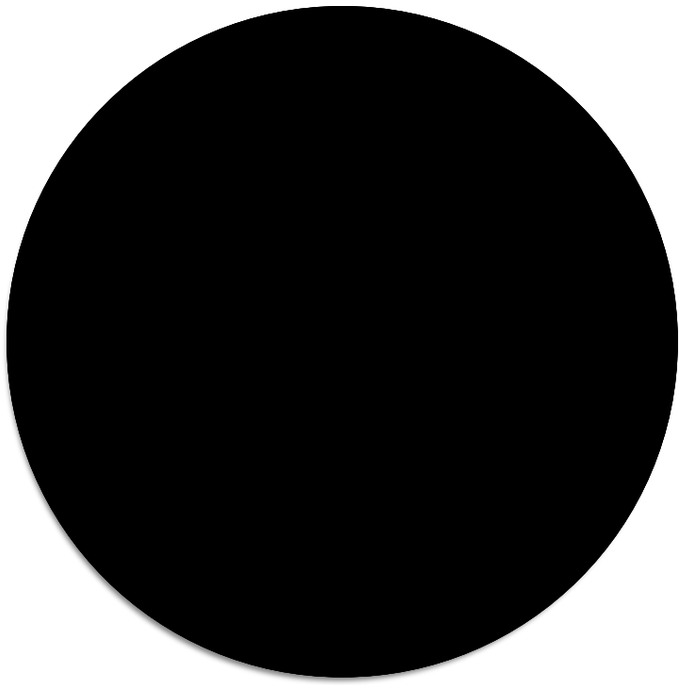
Mesoscopic modelling of the retina

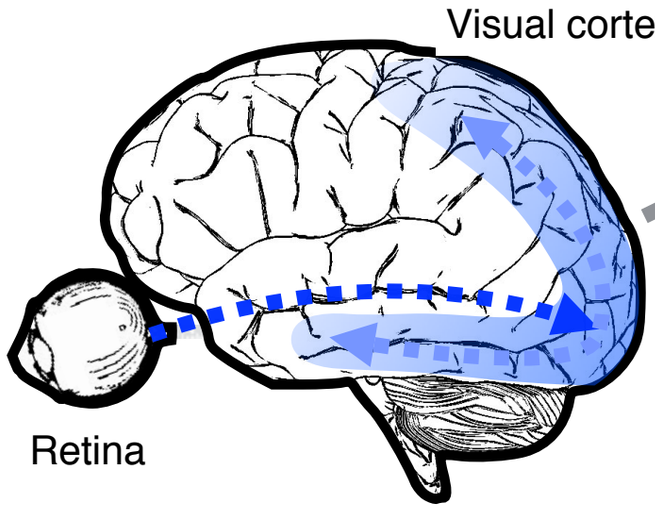
Collab.: Institut de la Vision, INLN-InPhyNi

D. Karvouniari, PhD (2014-2018)
Dir.: B. Cessac

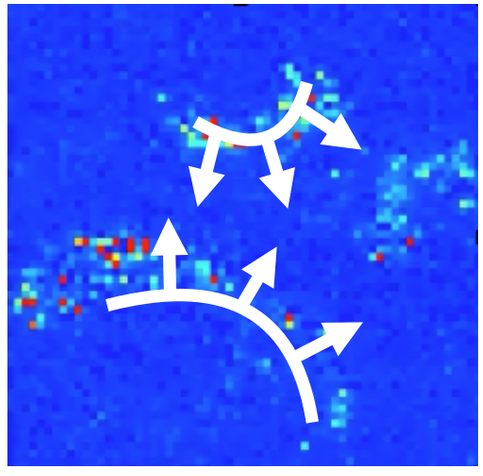
Visual system (re)-shaping: Retinal waves

Collab.: Institut de la Vision, INLN





Retinal **waves** during development
Courtesy E. Sernagor
University of Newcastle

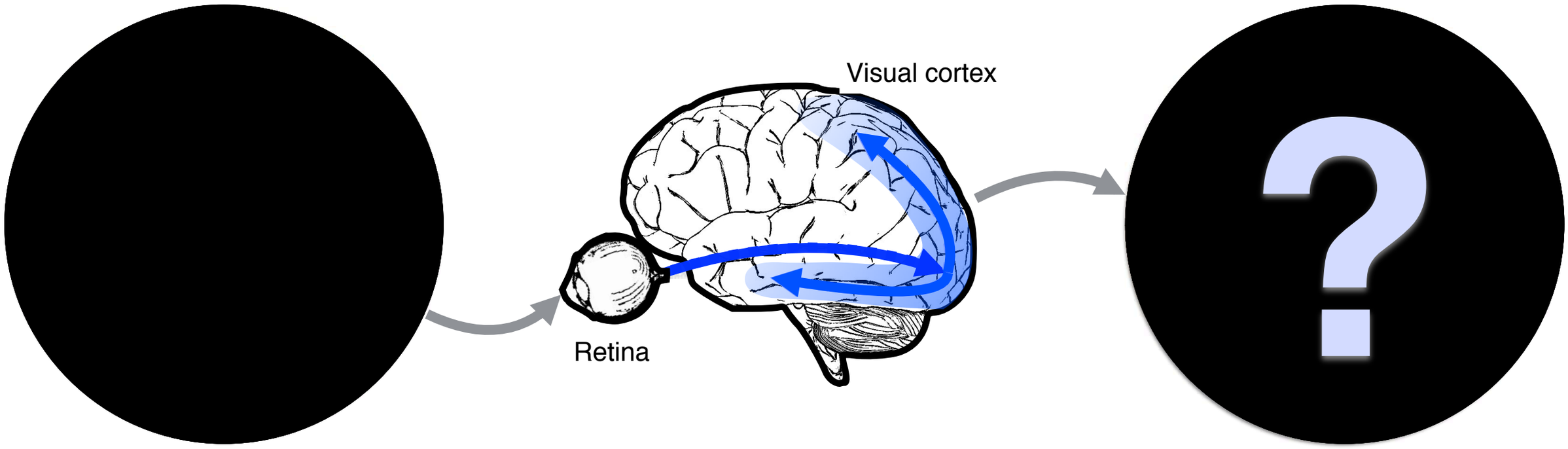


Retina: evolving medium with ongoing spatio-temporal activity

D. Karvouniari, PhD (2014-2018)
Dir.: B. Cessac

Visual system (re)-shaping: Retinal waves

Collab.: Institut de la Vision, INLN



D. Karvouniari, PhD (2014-2018)
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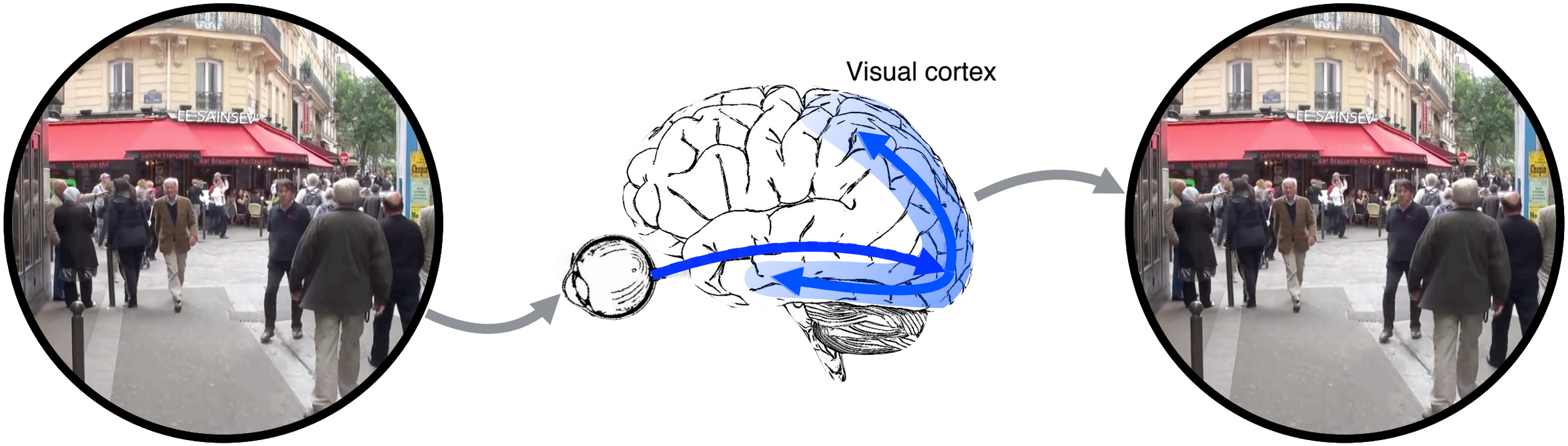
Visual system (re)-shaping: Retinal waves

Collab.: Institut de la Vision, INLN

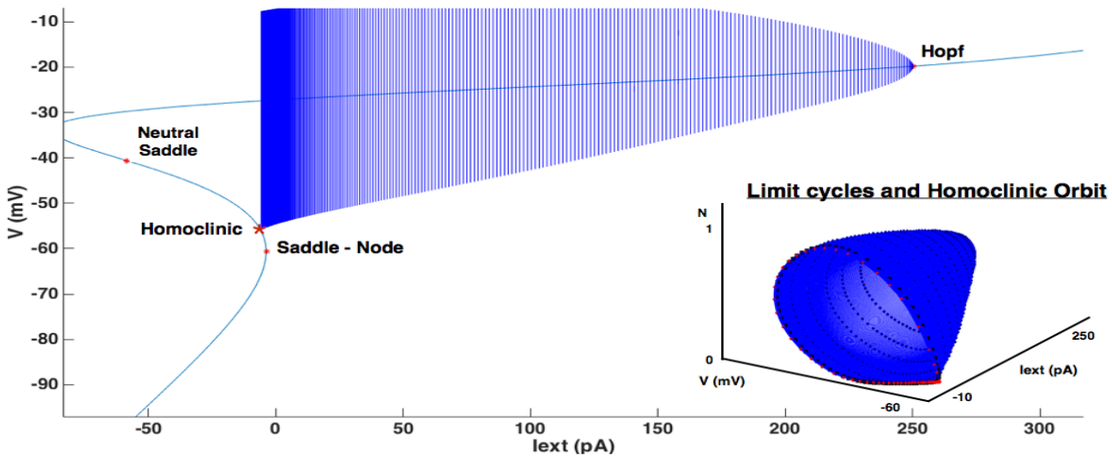


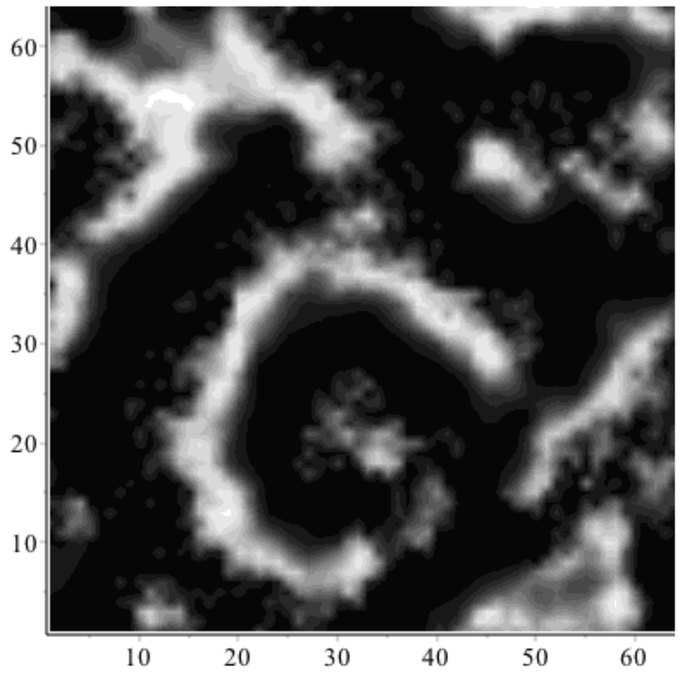
D. Karvouniari, PhD (2014-2018)
Dir.: B. Cessac

Visual system (re)-shaping: Retinal waves

Collab.: Institut de la Vision, INLN

Biophysical modelling (in agreement with experiments)
Dynamical system analysis





Dora Karvouniari, Lionel Gil, Olivier Marre, Serge Picaud, Bruno Cessac, A biophysical model explains the oscillatory behaviour of immature starburst amacrine cells (under review)

Toward a mesoscopic description of retina activity

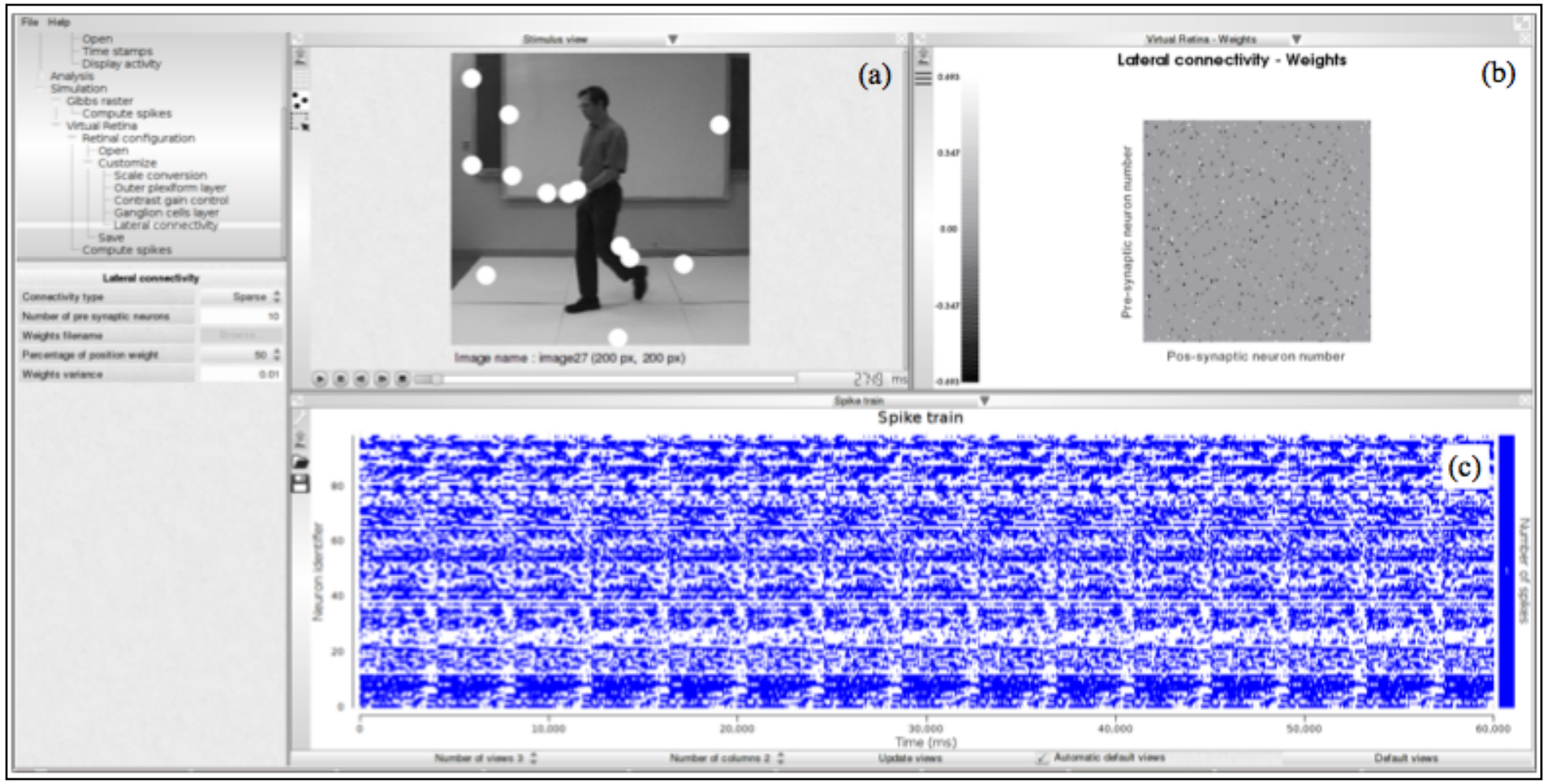
- Reduced equations, reduced parameters (« Reynolds like » number)
- Generic mechanisms of transport as a function of biophysical parameters

$$\frac{\partial G_A}{\partial t} = g_A D_M \left[(\nabla G_S, \nabla G_A)\, D_H^2 \begin{pmatrix} \nabla G_S \\ \nabla G_A \end{pmatrix} + \frac{\partial H}{\partial G_S} \Delta G_S + \frac{\partial H}{\partial G_A} \Delta G_A \right] + S(G_S, G_A).$$

Pharmacologically controlling the arousal of retinal waves in adults

Mesoscopic modelling of the retina

Producing software for biologists and physicians

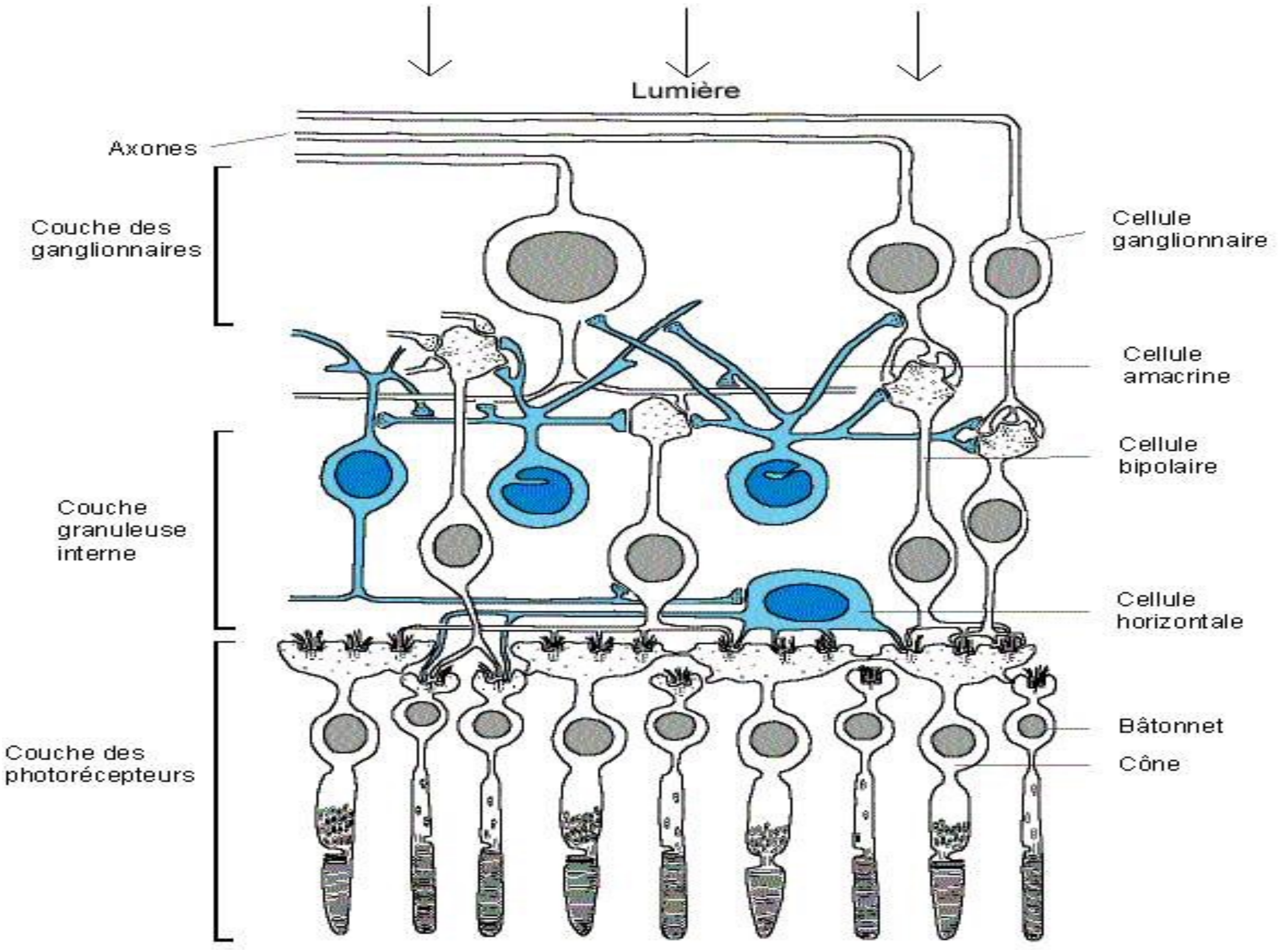


PRANAS: Platform for Retina ANalysis And Simulation

B. Cessac, P. Kornprobst, S. Kraria, H. Nasser, D. Pamplona, G. Portelli and T. Viéville, PRANAS: a new platform for retinal analysis and simulation, Frontiers in Neuroinformatics, 2017

https://pranas.inria.fr/

MACULAR: Numerical platform for large scale simulations of the retina in pathological conditions


Lumière
Axones
Couche des ganglionnaires
Couche granuleuse interne
Couche des photorécepteurs
Cellule ganglionnaire
Cellule amacrine
Cellule bipolaire
Cellule horizontale
Bâtonnet
Cône

Lumière

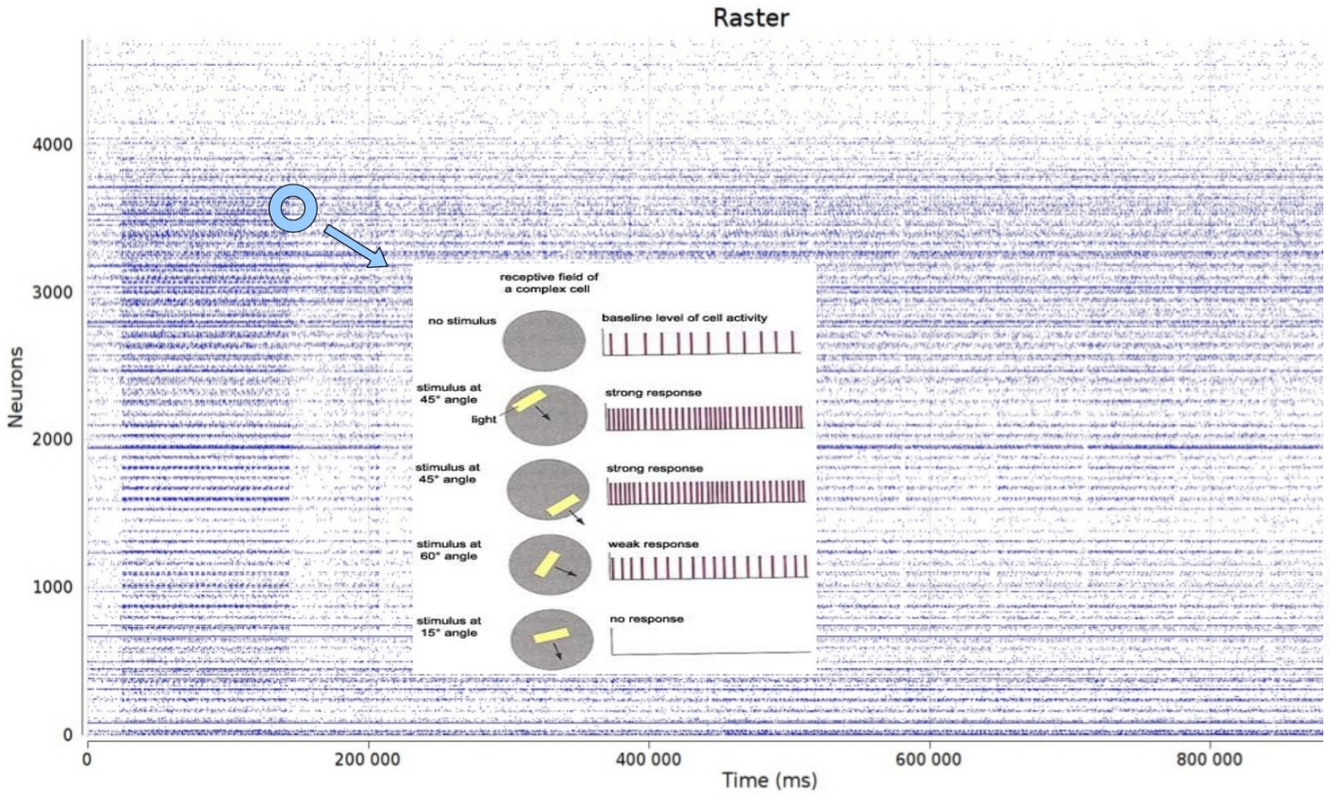
Axones

Couche des ganglionnaires

Cellule ganglionnaire

Couche granuleuse interne

Raster



Cellule amacrine

Cellule bipolaire

Cellule horizontale

Couche des photorécepteurs

Bâtonnet

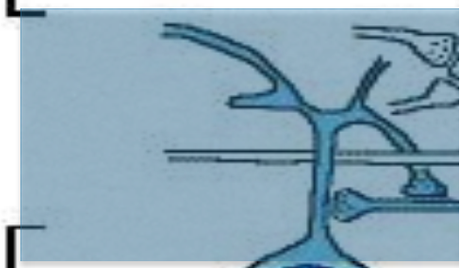
Cône

Lumière

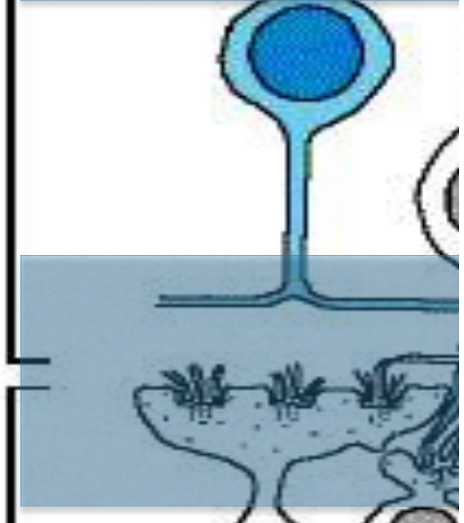
Axones

Couche des ganglionnaires

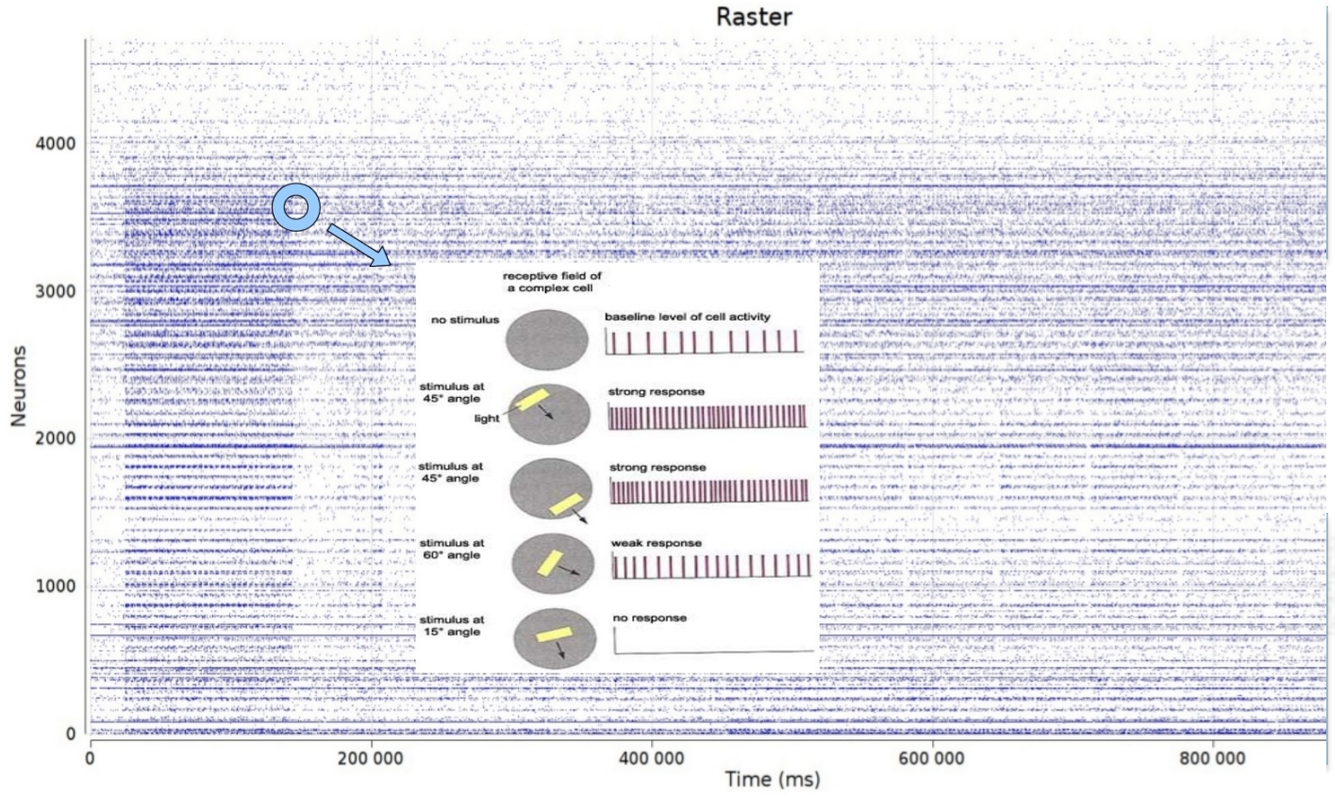
Cellule ganglionnaire



Couche granuleuse interne



Couche des photorécepteurs



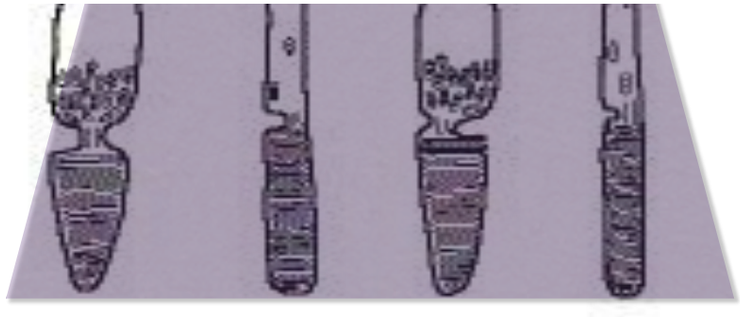
Cellule amacrine

Cellule bipolaire

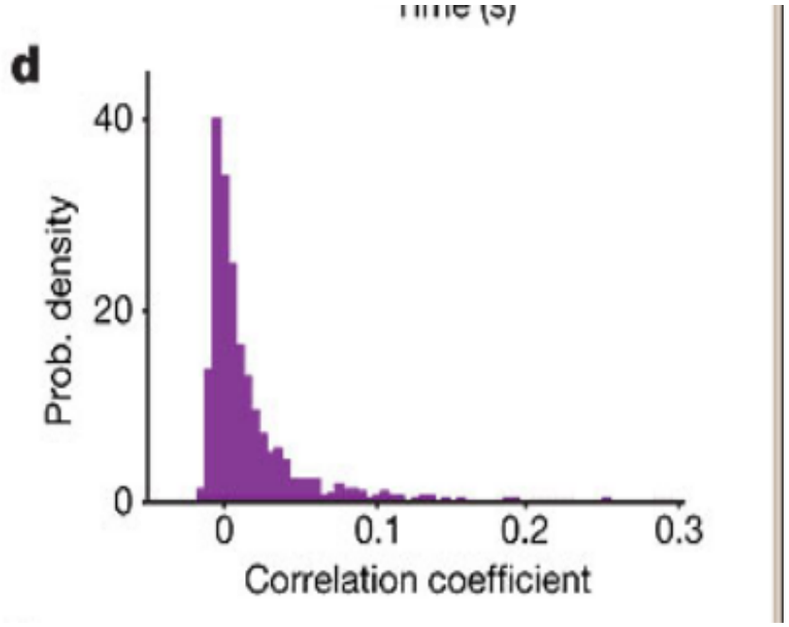
Cellule horizontale

Bâtonnet

Cône

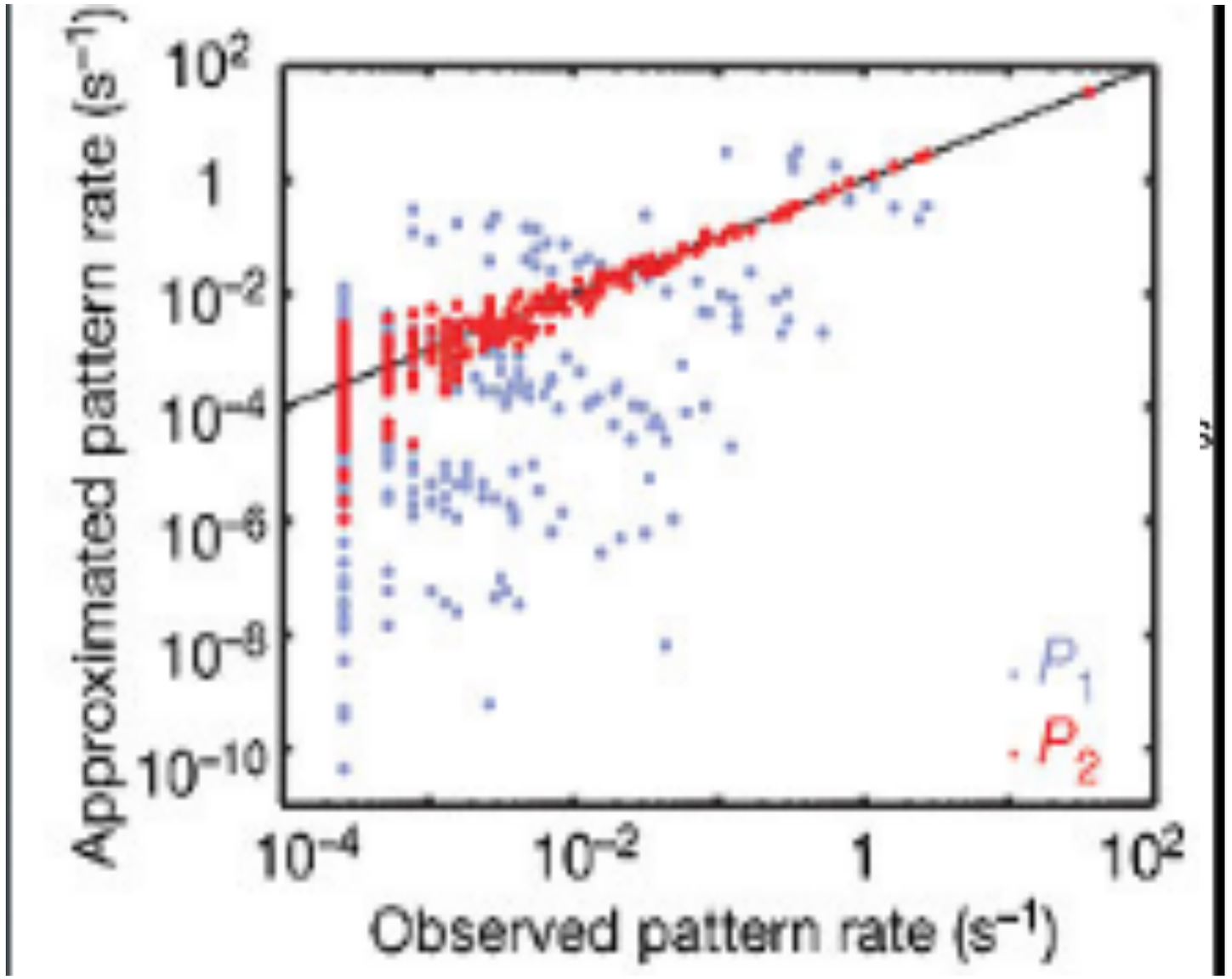


Reading the retinal neural code



Maximizing the statistical entropy under constraints

Ising model



Berry-et al, Nature, 2006

Extension to more general correlations

Stationary: Extended Gibbs distribution

(Vasquez-et-al, 2011; Nasser et al 2013, Coffré-Cessac; 2014)

Non stationary: Linear response theory

Cessac-Coffré, 2017

e spatio-temporal correlations modified by a moving object ?

Souihel et al, in progress

Evgenia Kartsaki, PhD (2017-2020)
co-dir.: B. Cessac & E. Sernagor

Pharmacologically induced pathologies

Population level: switching on and off cell types

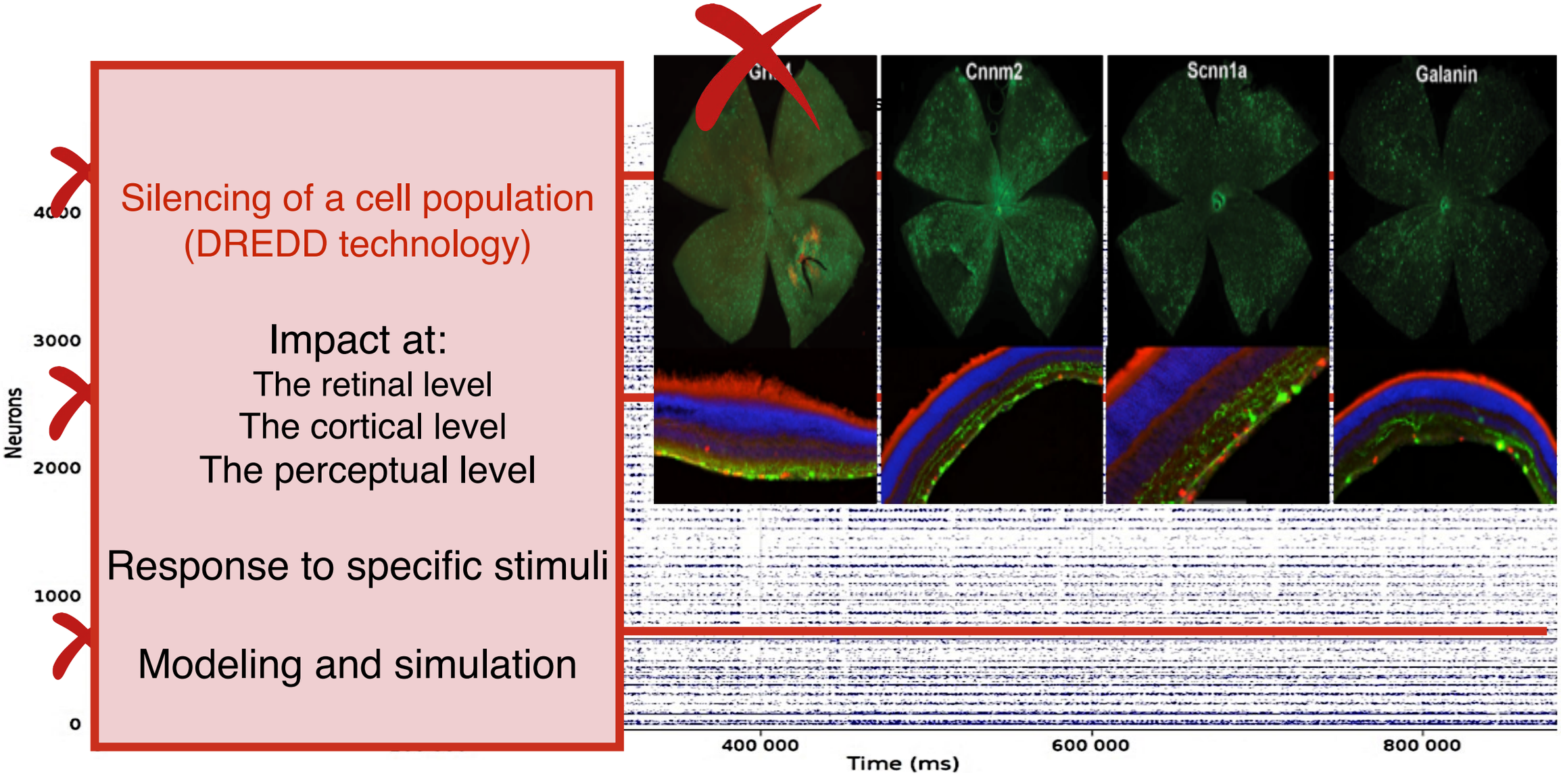
Collab.: University of Newcastle, University of Edinburgh
Leverhulme Funding (2017-2020)

Silencing of a cell population
(DREDD technology)

Impact at:
The retinal level
The cortical level
The perceptual level

Response to specific stimuli

Modeling and simulation



Selma Souihel, PhD (2016-2019)
Dir.: B. Cessac

Motion anticipation

Collab.: INT Marseille, IdV Paris, University of Valparaiso

ANR Trajectory (2016-2020)

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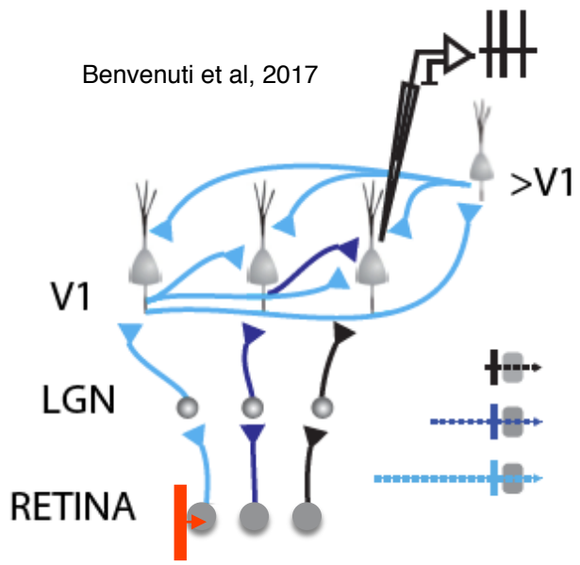
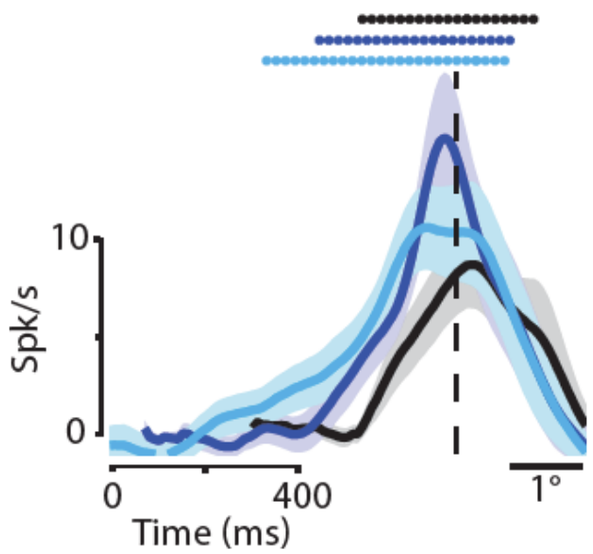




From retina … to cortex

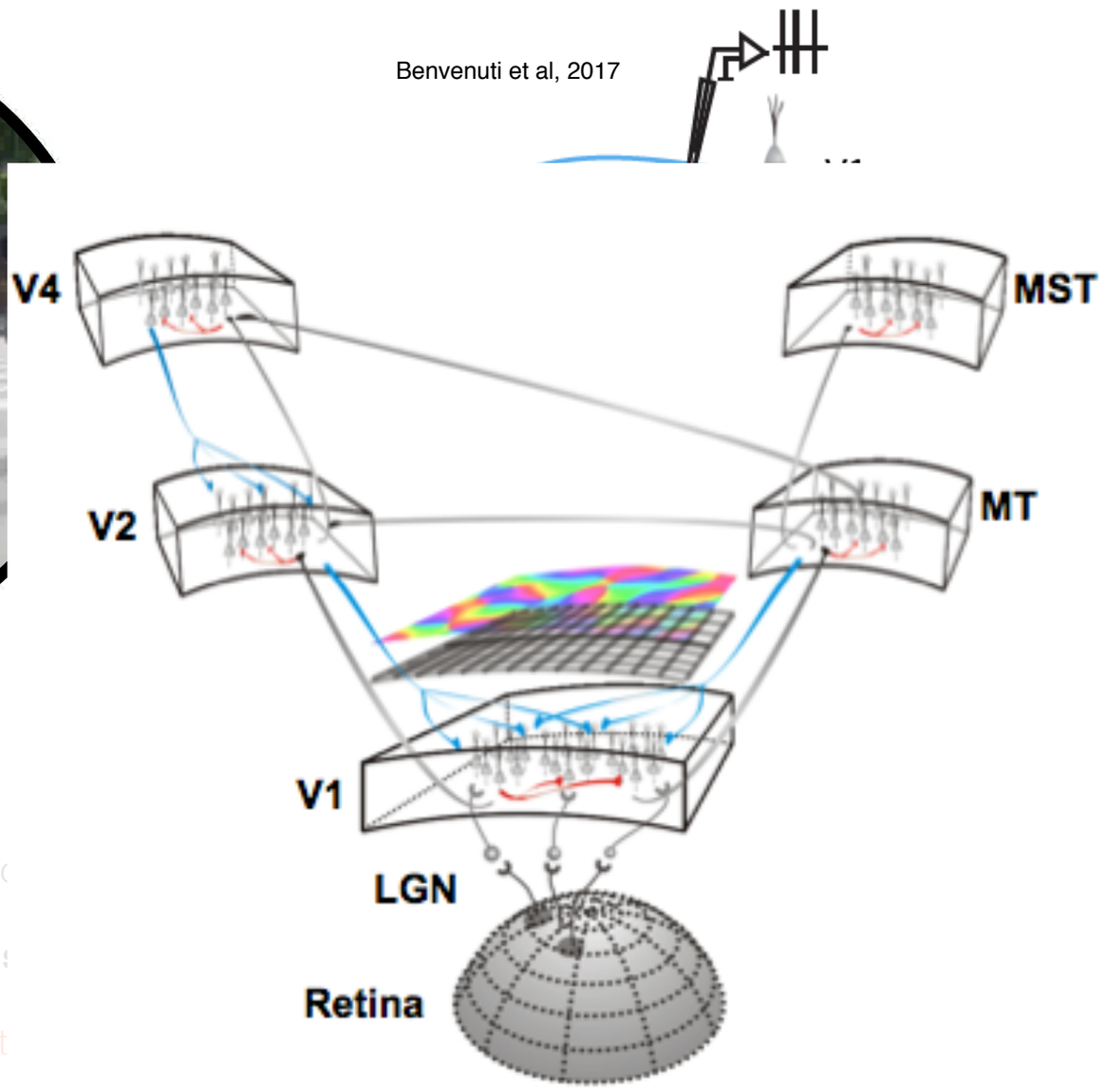
Selma Souihel, PhD (2016-2019)
Dir.: B. Cessac

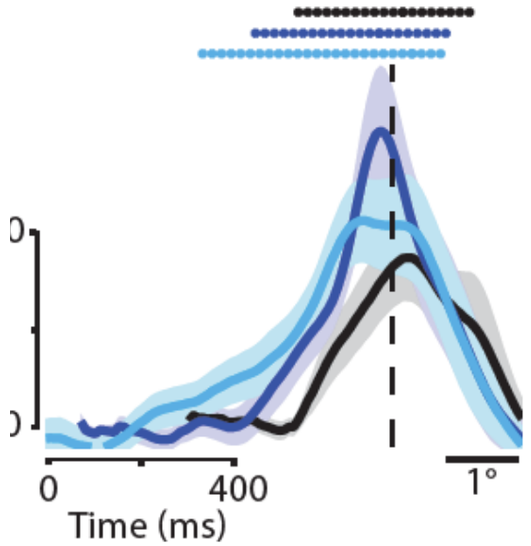
Motion anticipation

Collab.: INT Marseille, IdV Paris, University of Valparaiso

ANR Trajectory (2016-2020)

Benvenuti et al, 2017





At a population c na to cortex

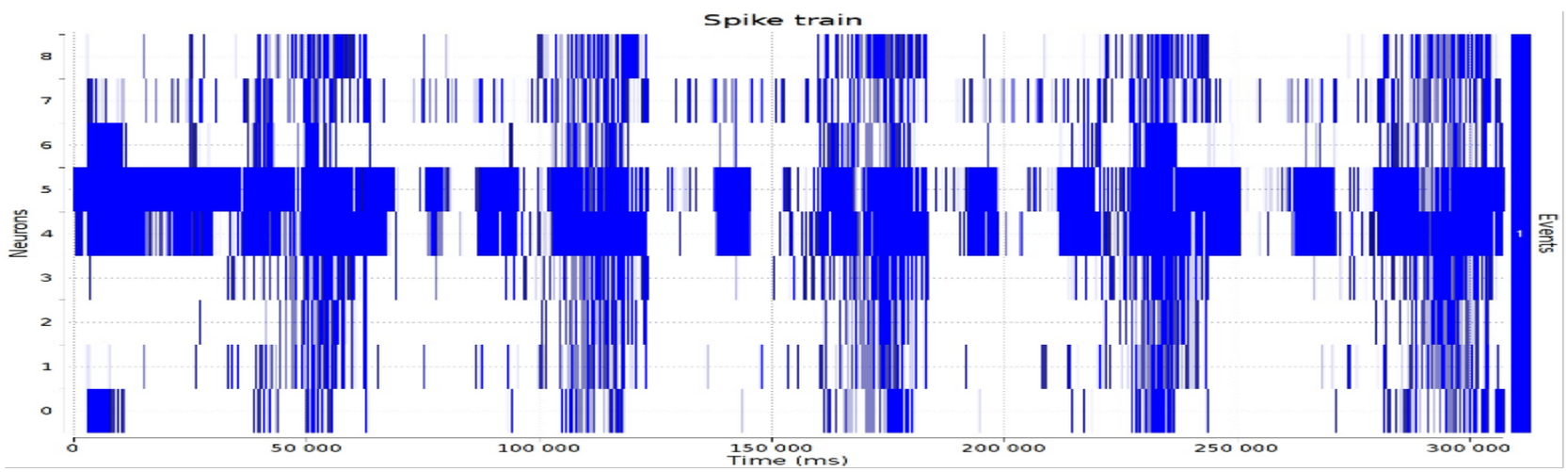
Spatio-temporal correlation

Cessac et nded model with a realistic **retino -**
cing cortical activity (**VSDI**) in V1.

PRANAS => **realistic entry** to a V1 model.

- Hierarchical model of the visual cortex motion areas.

How is motion imprinted in the spike train ?

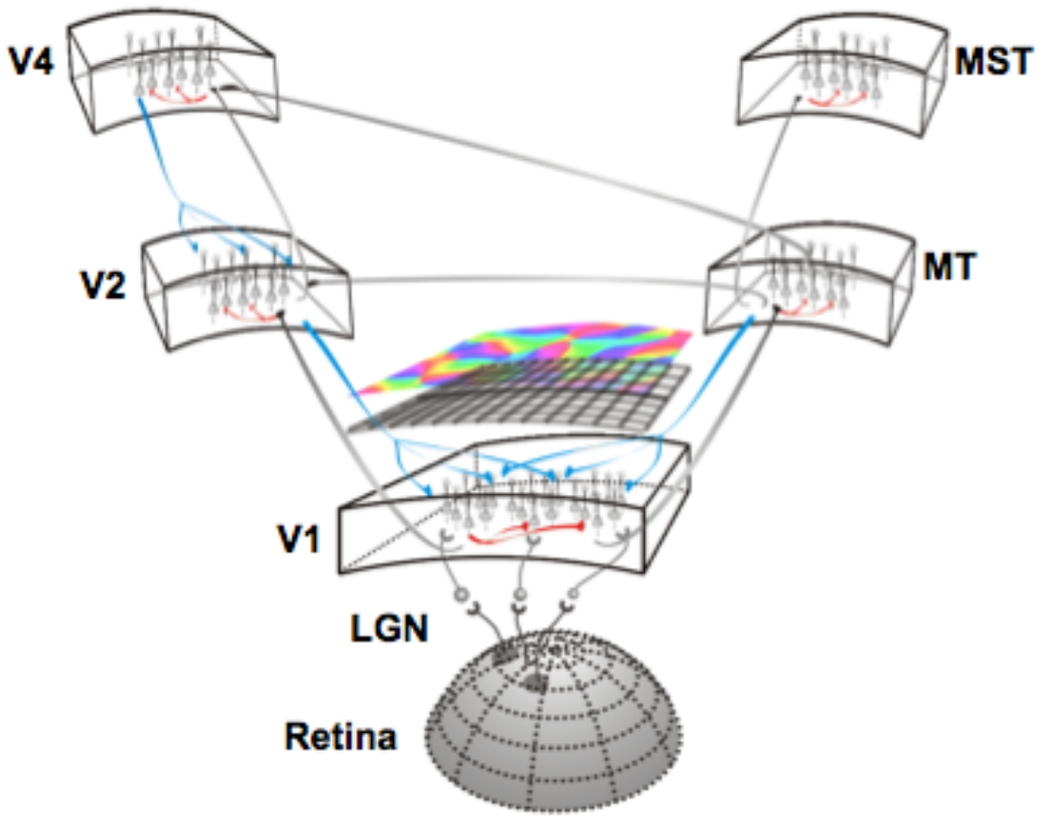


Selma Souihel, PhD (2016-2019)
Dir.: B. Cessac

Motion anticipation

Collab.: INT Marseille, IdV Paris, University of Valparaiso
ANR Trajectory (2016-2020)

From retina … **to cortex**



Realistic input

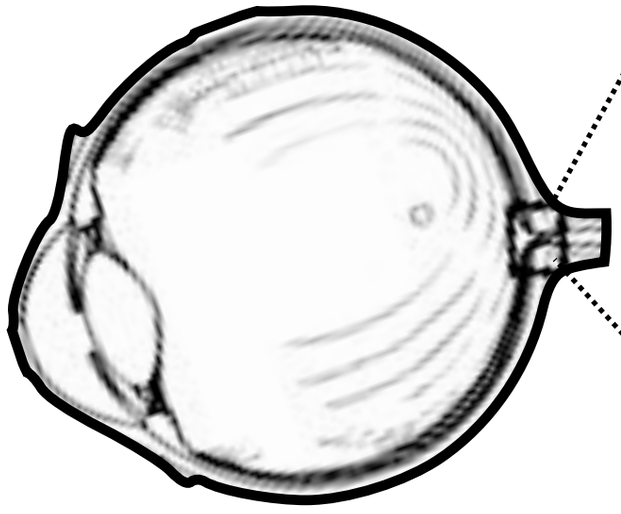
- Integrated models: From retina to cortex

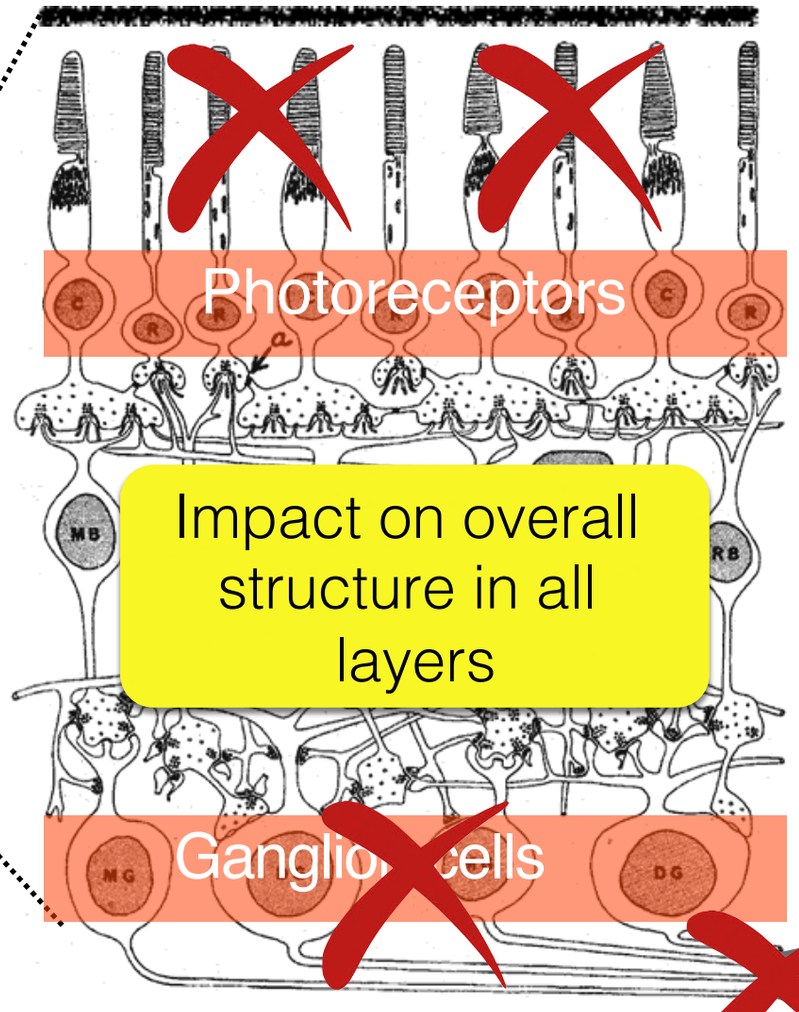
Model:

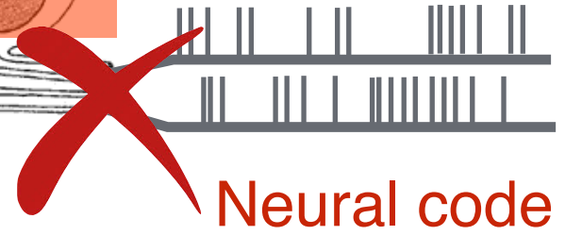
- Reduced spatially extended model with a realistic **retino -thalamic** input reproducing cortical activity (**VSDI**) in V1.

- Hierarchical model of the visual cortex motion areas.

The retina







Neural code

Blindness

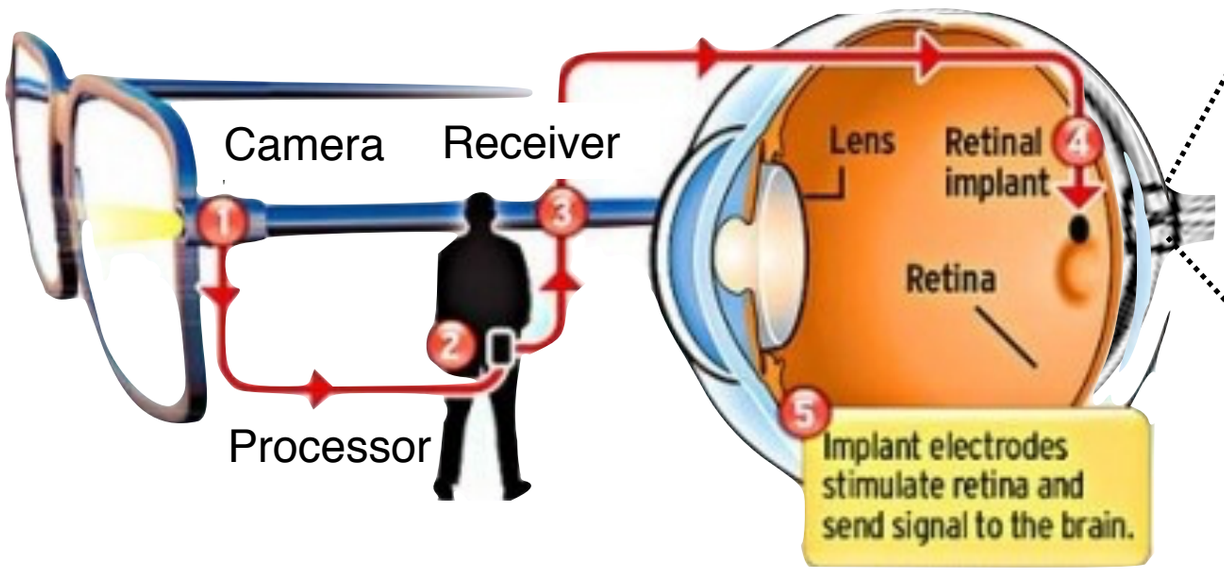
Existing emerging therapeutic methods

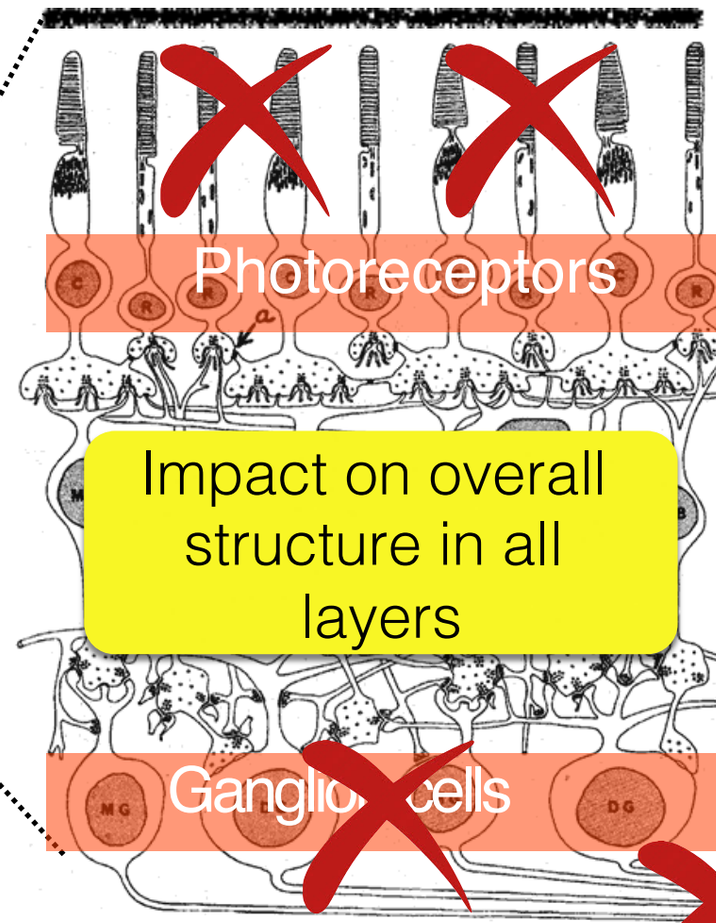
Gene therapy

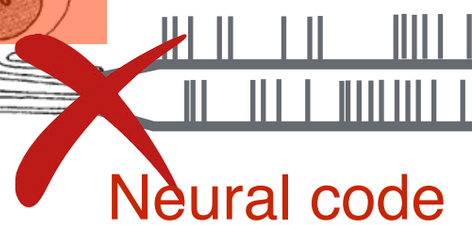
Stem cells

Cell transplantation

Retinal prostheses
(electric, optoelectronic, optogenetic)

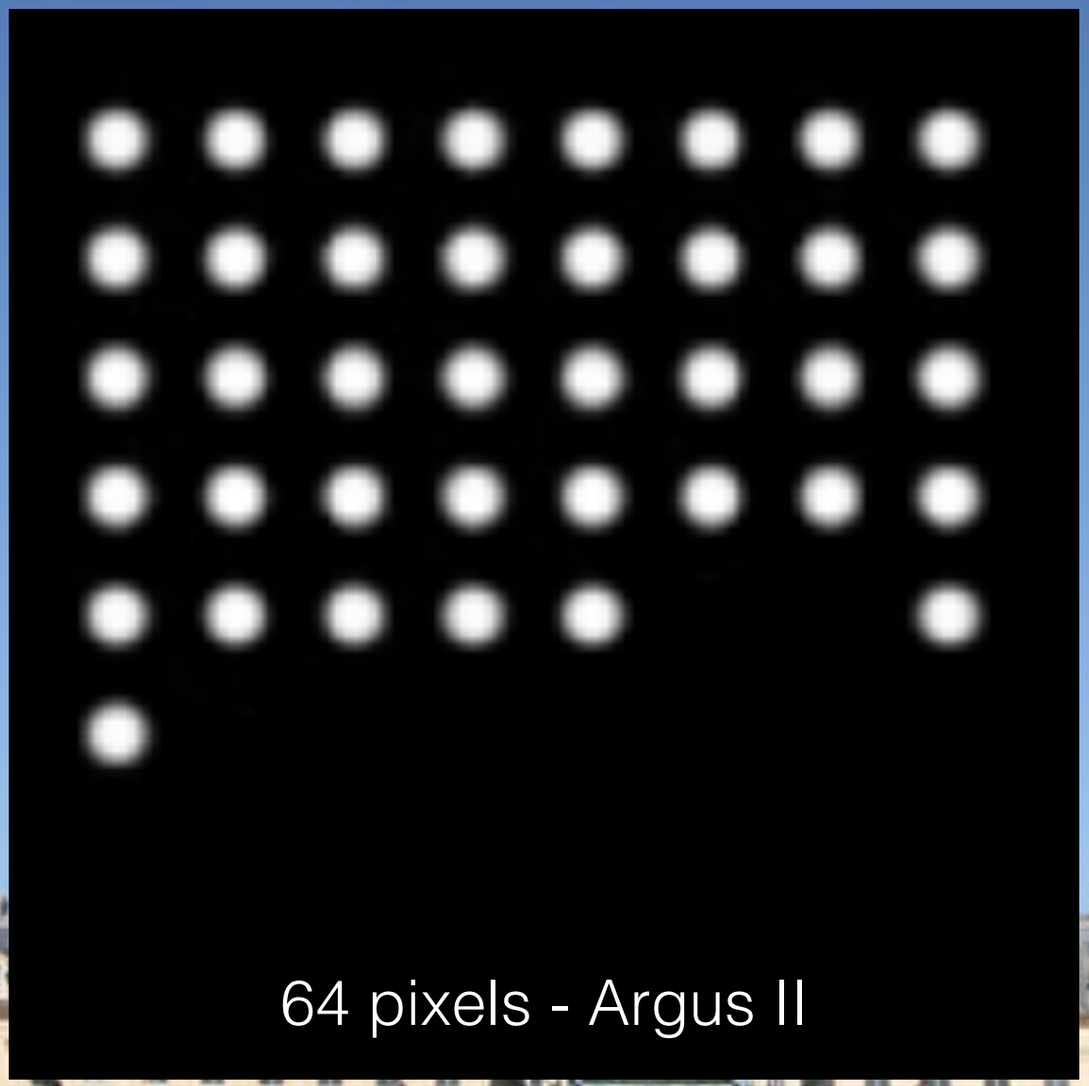






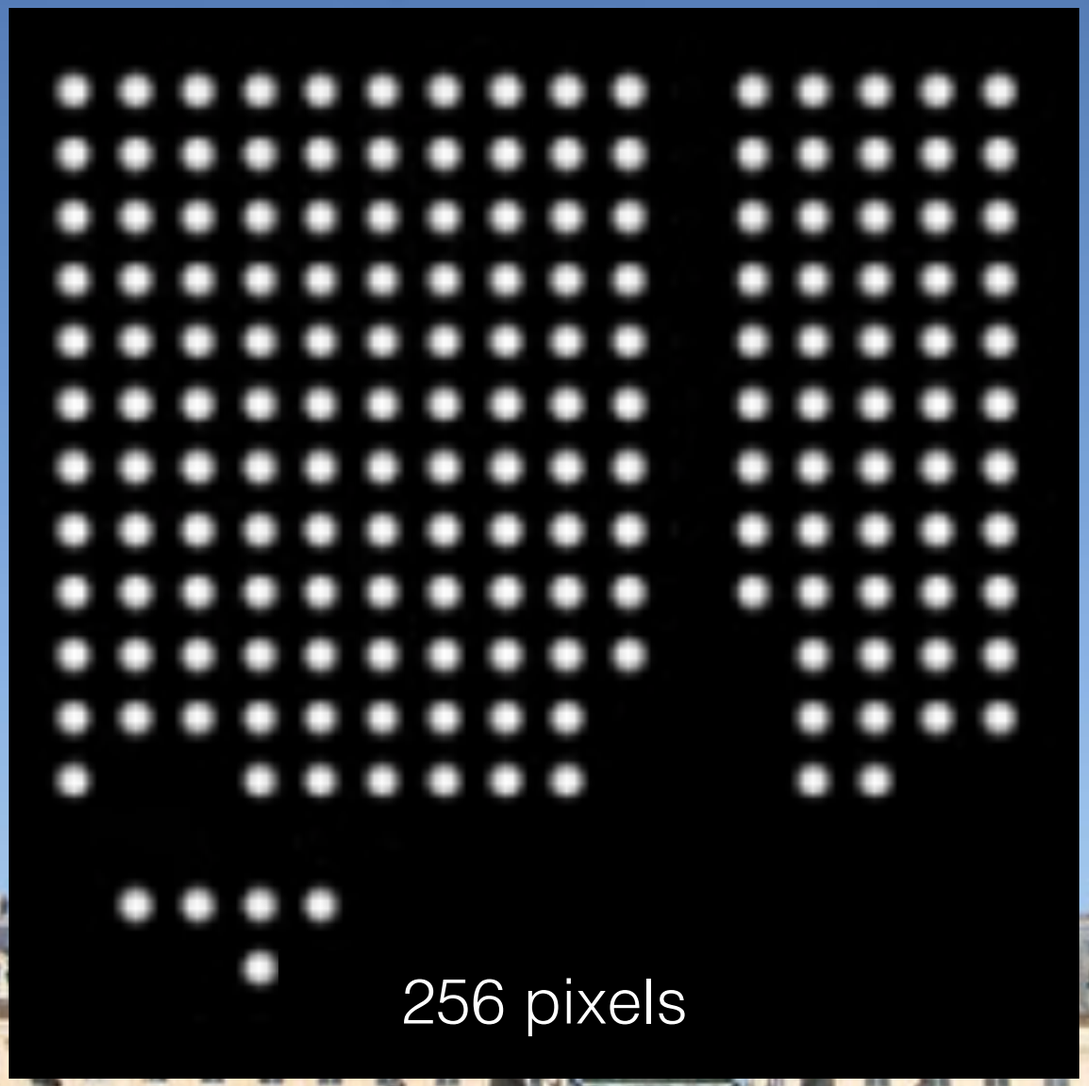
Adapted from Institut de la Vision

Adapted from Institut de la Vision



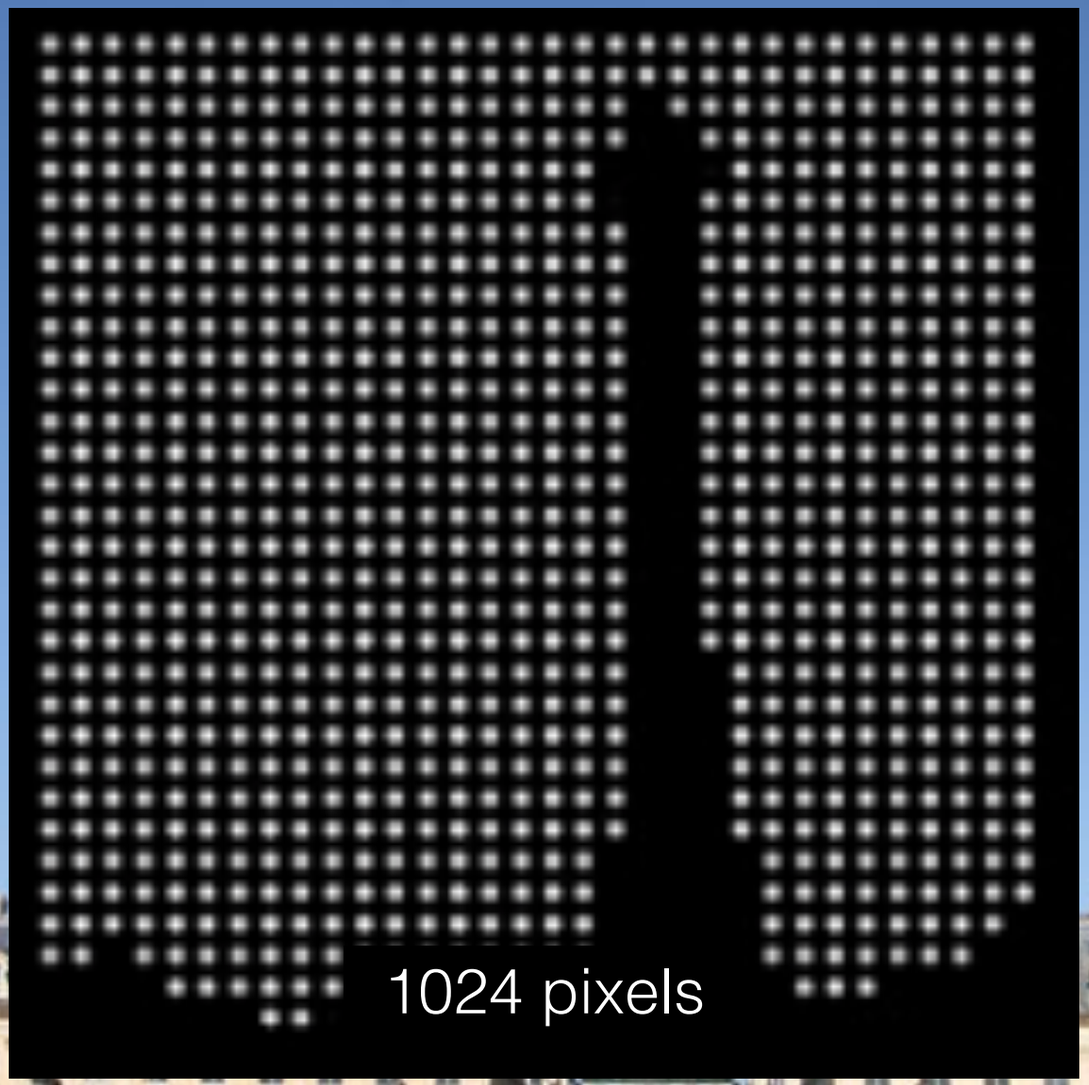
64 pixels - Argus II

Adapted from Institut de la Vision



256 pixels

Adapted from Institut de la Vision



1024 pixels

Extract content from
a visual scene

Adapted processing

Static vs motion